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# Piezoelectric-Driven Charging Supercapacitors For Bio-Medical Sensor Applications

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## Abstract

*Piezoelectric materials can be fabricated as a generator to transform mechanical energy in ambient vibration into electrical energy, which can be stored and used to power some ultra- low power devices such as radio frequency identification (RFID) tags. Since most of the ultra-low power devices are wireless, it becomes essential to have their own independent power supplies. In tradition, the power supplies come from bulky lead acid and lithium batteries, which have environment unfriendly chemical ingredients. Most importantly, the lead acid and lithium batteries have limited life of 500-1000 cycles compared to millions or more for most commercially available carbon based Supercapacitor. With the introduction of many portable electronic device and health monitor device using Piezo based energy harvesting has become one of the fascinating subjects of interest to provide portable electrical power.*

**Keywords:** *Piezoelectric; Supercapacitor; Ultra-low power devices; Wireless*

## 1. INTRODUCTION

Piezoelectric energy harvesting has been proved to be a novel solution to replace the lead acid and lithium batteries in remote power supply applications. Unfortunately, the limited power capacity and low efficiency of output power constraint the practical applications of energy harvesting in daily life shows as Fig. 1. After a literature review of current researches about piezoelectric energy harvesting in power management perspective, a circuit design, which focuses on low-frequency mechanical vibration, is introduced. Piezoelectric energy can be used for small scale energy harvesting because of its high energy storage density. Energy harvesting involves harvesting electrical power convert and storing of the harvested power. The reason for choosing piezoelectricity is because of its higher energy storage density as it has been justified earlier shows as Fig. 4. In piezoelectric energy harvesting, piezoelectric sensor is used as a harvesting element and the storage element is a Supercapacitor. Recent advances in ultralow power microcontrollers have produced devices that offer unprecedented levels of integration for the amount of power they require to operate. These are systems on a chip with aggressive power saving schemes, such as shutting down power to idle functions. In fact, so little power is needed to run these devices that many sensors are going wireless, since they can readily run from batteries. Unfortunately, batteries must be regularly replaced, which is a costly and cumbersome maintenance project. A more effective wireless power solution may be to harvest ambient mechanical, thermal, or electro-magnetic energy in the sensor's local environment Fig. 2.

Analog Devices offers a wide range of ultra-low power ICs for energy harvesting applications. Power management products that convert energy from vibration (piezoelectric), photovoltaic (solar), and thermal (TEC, TEG, thermopiles, thermocouples) sources provide high efficiency conversion to regulated voltages or to charge batteries and super capacitor storage elements. Boost converters that operate from as little as 20 mV or battery chargers with maximum power point capability expand the possibilities for industrial automation and control, wireless sensor, transportation, automotive and building management applications. Ultra low quiescent current linear regulators, op amps, comparators, voltage supervisors, ADCs, DACs, and micro power voltage references provide additional building blocks for autonomous systems shows as Fig. 3.

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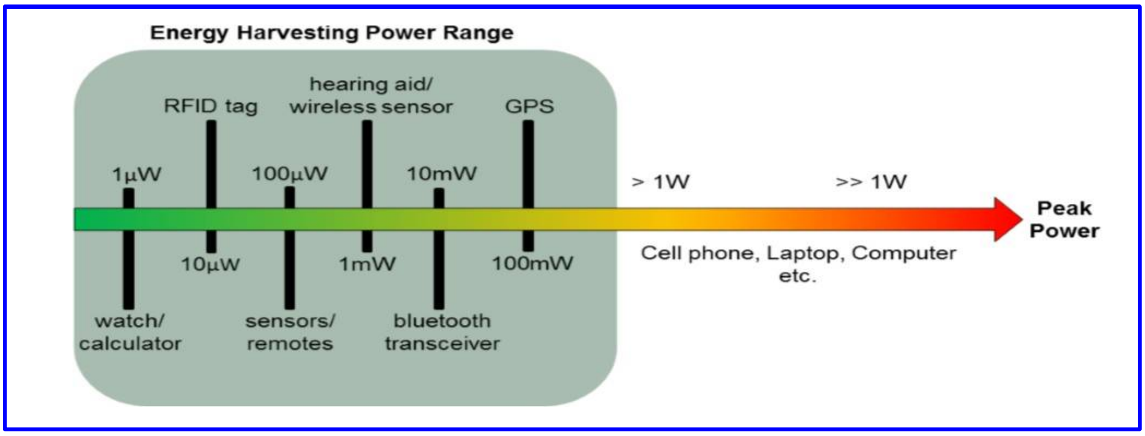


**Fig. 1: Schematic diagram of Energy harvesting power range**

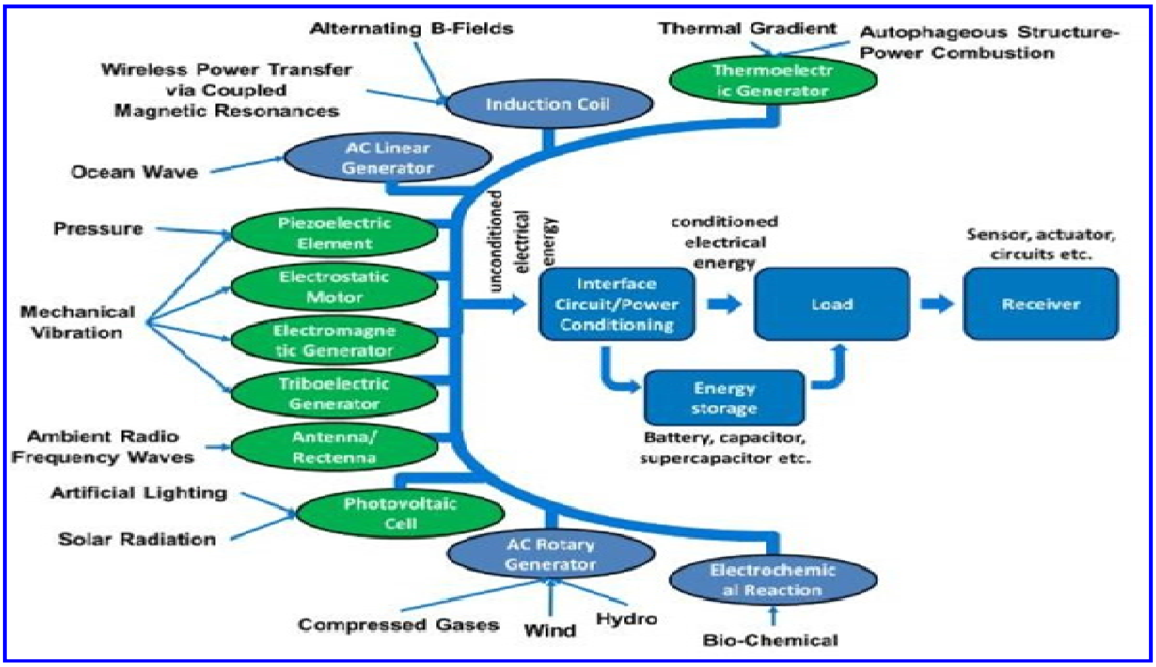


**Fig. 2: Schematic diagram of ambient energy source energy harvesting technologies**

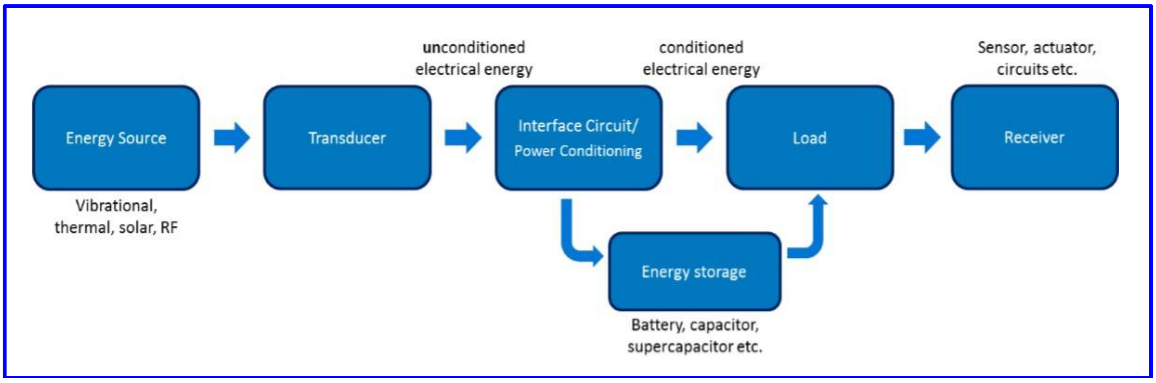


**Fig. 3: Block diagram of Energy harvesting system**

The environment has abundant energy, so energy harvesters are an ideal power source for IoT applications, eliminating the need to replace and dispose of batteries. However, small energy harvesters often cannot provide the peak power required to collect and transmit data. This article will show how to use a supercapacitor charged from an energy harvester to provide the peak power required using a small solar cell as a case study. The typical power architecture has an energy harvester supplying a supercapacitor charging circuit with the supercapacitor directly supplying the load. The high C and low ESR of the supercapacitor maintains a sufficiently stable voltage for the load to function during its peak power bursts.

## 2. MATERIALS & METHODOLOGY

Ambient energy sources include light, heat differentials, vibrating beams, transmitted RF signals or any other source that can produce an electrical charge through a transducer. For instance,

- Small solar panels have been powering handheld electronic devices for years and can produce 100s of mW/cm2 in direct sunlight and 100s of µW/cm2 in indirect light.
- Seebeck devices convert heat energy into electrical energy where a temperature gradient is present. Sources of heat energy vary from body heat, which can produce 10s of µW/cm2 to a furnace exhaust stack where surface temperatures can produce 10s of mW/cm2.
- Piezoelectric devices produce energy by either compression or deflection of the device. Piezoelectric elements can produce 100s of µW/cm2 depending on their size and construction.
- RF energy harvesting is collected by an antenna and can produce 100s of pW/cm2.

Successfully designing a completely self-contained wireless sensor system requires power- saving microcontrollers and transducers that consume minimal electrical energy from low energy environments. Now that both are readily available, the missing link is the high efficiency power conversion product capable of converting the transducer output to a usable voltage.

The LTC3588-1 shown in Fig. 6 is a complete energy harvesting solution optimized for high impedance sources such as piezoelectric transducers. It contains a low loss full wave bridge rectifier and a high efficiency synchronous buck converter, which transfer energy from an input storage device to an output at a regulated voltage capable of supporting loads up to 100mA. The LTC3588-1 is available in 10-lead MSE and 3mm × 3mm DFN packages.

Fig. 5 shows an energy harvesting power system that includes the energy source/transducer, an energy storage element and a means to convert this stored energy into a useful regulated voltage. There may also be a need for a voltage rectifier network between the energy transducer and the energy storage element to prevent energy from back-feeding into the transducer or to rectify an AC signal in the case of a piezoelectric device.

Application Examples LTC3588-1 requires the output voltage of the transducer to be above the under voltage lockout rising threshold limit for the specific output voltage set at the D0 and D1 input pins. For maximum energy transfer, the energy transducer must have an open circuit voltage of twice the input operating voltage and a short-circuit current of twice the input current required. These requirements must be met at the minimum excitation level of the source to achieve continuous output power.

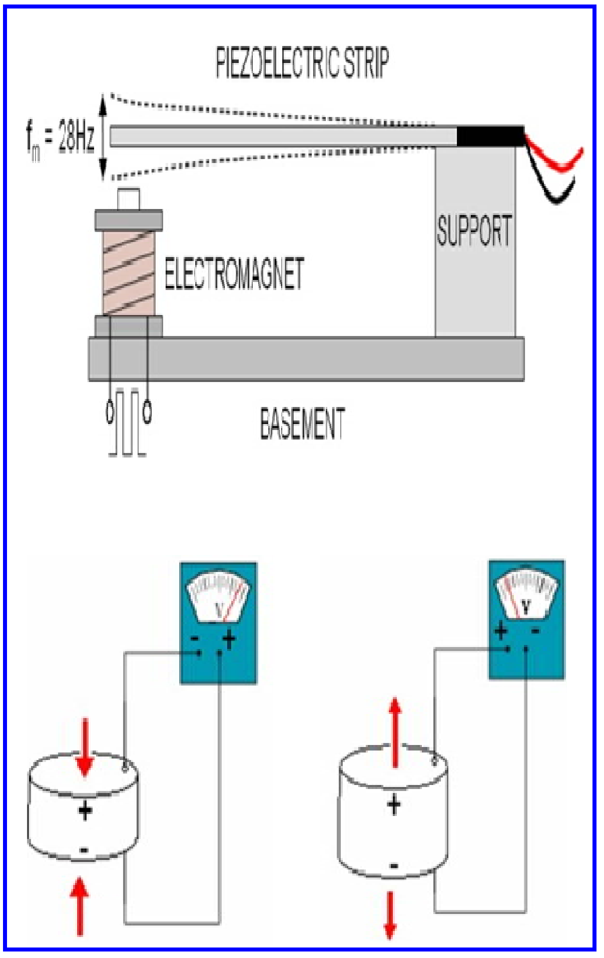


**Fig. 4: Block diagram of principle of piezoelectric materials**

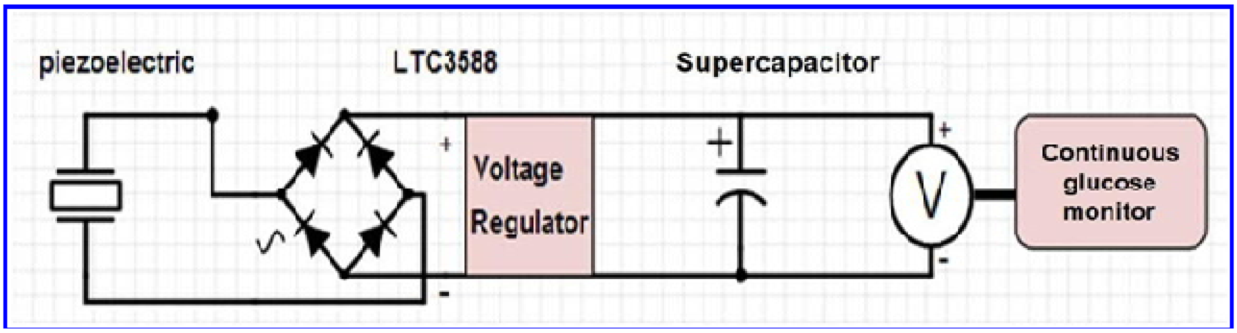


**Fig. 5: Equivalent circuit diagram of Piezoelectric-driven charging Supercapacitor**

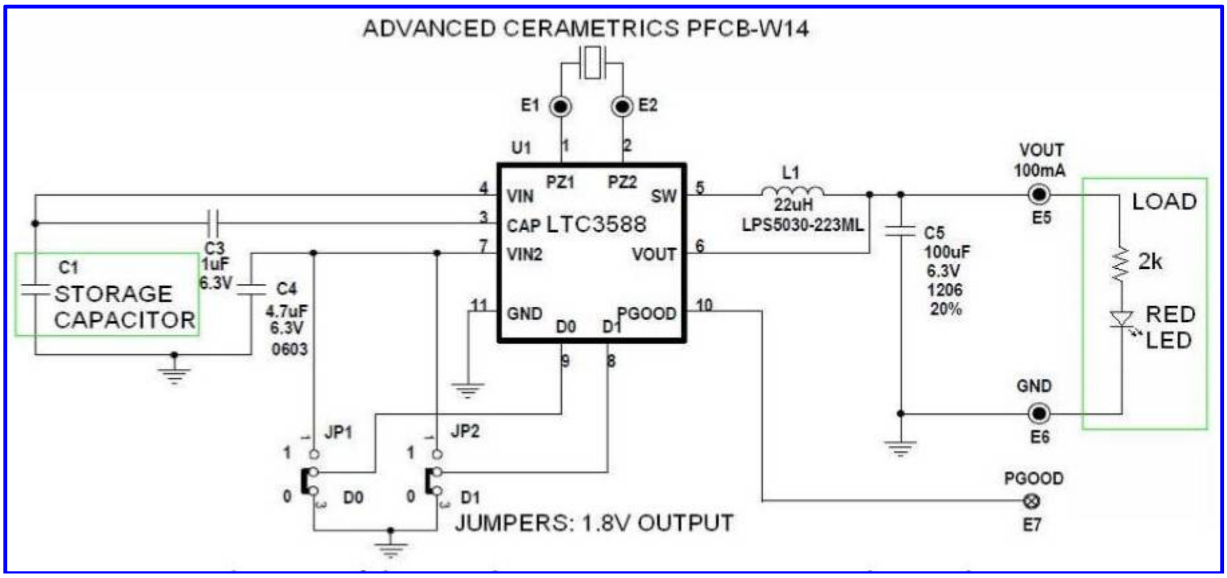


**Fig. 6: Charging circuit diagram of Piezoelectric-driven charging Supercapacitor**

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Piezoelectric Transducer Application Fig. shows a piezoelectric system that, when placed in an air stream, produces 100µW of power at 3.3V. The deflection of the piezoelectric element is 0.5cm at a frequency of 50Hz.

Harvesting mechanical energy from human motion is an attractive approach for obtaining clean and sustainable electric energy. Piezoelectricity is electrical energy produced from mechanical pressure (such as walking, running). When pressure is applied to an object, a negative charge is produced on the expanded side and a positive charge on the compressed side of the piezoelectric crystal. Once the pressure is relieved, electrical current flows across the material. The commonly used sources are: solar power, wind energy and piezoelectricity. This study is focussed on Piezoelectricity as it depends on the mechanical pressure or strains to obtain electrical energy, while the other sources are not reliable at all times. The comparison of energy storage density between the three generators. The piezoelectric has more energy storage density when compared with the other techniques.

## 3. RESULTS

Piezoelectric sensors have to be positioned in two main parts of the sole of the shoe where the maximum pressure is applied. The Piezo electric generator is placed inside a Shoe. A shoe has two points where the pressure exerted in maximum and they are the heel and the toe, and this is the exact place where the piezo electric unit is placed. Fig. 7. Shows the arrangement of the piezoelectric generator inside a shoe. Single sensor is capable of generating 3-5V on application of pressure consistently, in this work four sensors are connected in parallel in order to increase the probability of getting maximum output. Piezopolymeric materials are more advantageous to use than piezoceramic materials in case of sensor application, because polymeric films can be

easily fabricated to different shapes. Even then piezoceramic sensor has been used in this work because it is commercially available at low cost.

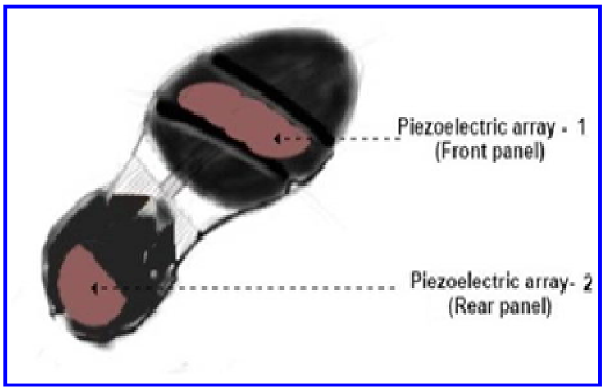


**Fig. 7: Arrangement of piezoelectric generator inside a shoe**

The design consists of a pair of array of piezo electric generator units connected in series. The Font panel has the array of piezo electric generator in a linear arrangement and the rear panel with a circular arrangement. The receiving and charging side collects intermittent or continuous energy input from the piezo generator and efficiently stores their energy in the capacitor bank. During the charging process, the capacitor voltage is continuously monitored. When it reaches 5.2V the module output is enabled to supply power to a Rectifier and charging unit.

A Piezoelectric disk type generator is placed in the shoe. When a person walks, pressure is exerted on the ground and this pressure can be converted into electrical energy and it can be used to charge the Supercapacitor. In this energy storage system using biomedical sensor applications.

There are many researches that successfully realize energy harvesting in the labs, but the total power efficiencies of the designed systems are constrained by the trade-off among efficiencies of each subsystems. For instance, some researchers pay much attention to maximizing the output power of the piezoelectric source, but the useful power stored in the energy buffer is degraded by the significant power dissipation of the regulator. Based on systematic analysis of piezoelectric energy harvesting in power management perspective, the maximum charging current of a Supercapacitor with optimized duty cycle is investigated.

Piezoelectric disk type generator, the maximum charging current of Supercapacitor can be obtained by optimizing the duty cycle of a buck regulator through software implemented pulse width modulation. The results of experiments prove the capacitive electric model of the piezoelectric generator, the existence of maximum charging current of the Supercapacitor, and the adaptive control of the designed circuits are shown Fig. 8 & 9.

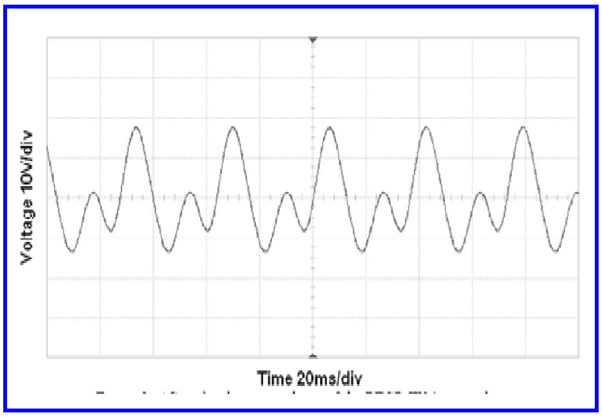


**Fig. 8: Piezoelectric generator output voltage**

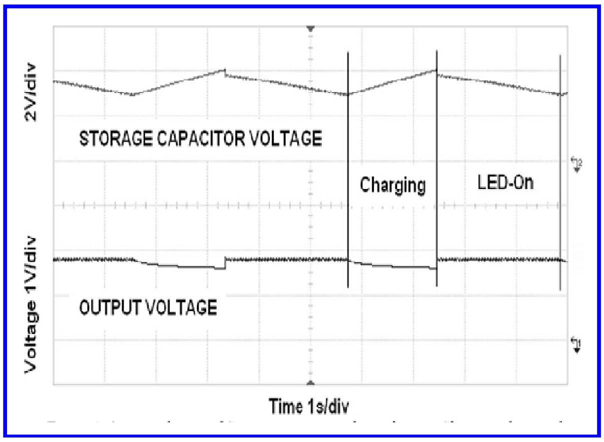


**Fig. 9: Piezoelectric driven Supercapacitor charging and discharging characteristics**

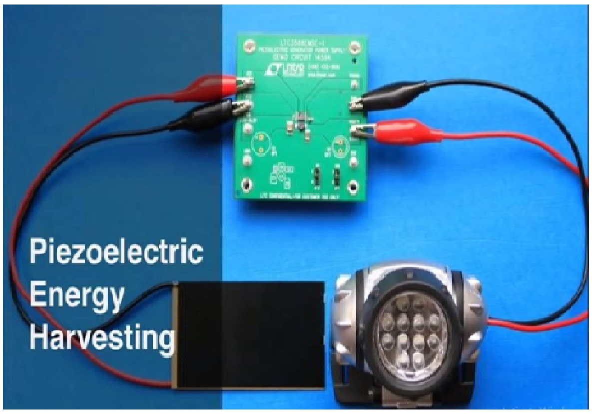


**Fig. 10: Hardware implementation Piezoelectric driven Supercapacitor setup**

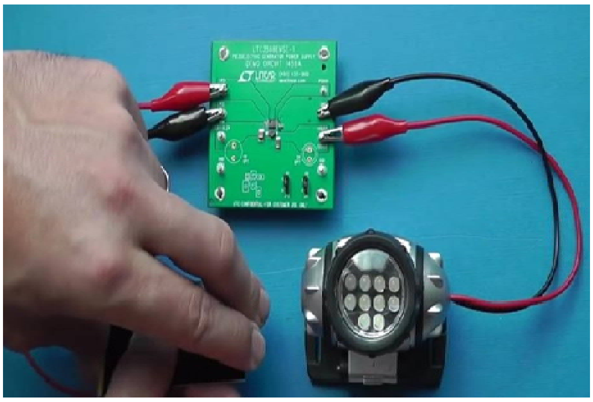

**Fig. 11: Piezoelectric driven charging Supercapacitor**

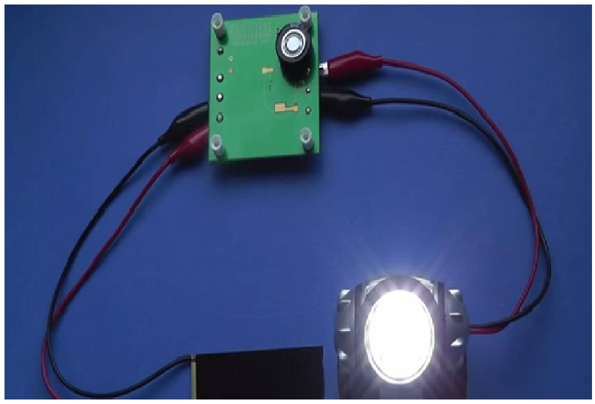

**Fig. 12: Piezoelectric driven charging Supercapacitor for LED Flash application**


**Fig. 13: Continuous Glucose Monitoring (CGM) Sensor, Receiver and Transmitter**

Continuous Glucose Monitoring (CGM) systems track glucose levels throughout the day. CGM users insert a tiny sensor wire just under their skin using an automatic applicator is shown Fig. 13. An adhesive patch holds the CGM sensor housing in place so the sensor can measure glucose readings in interstitial fluid throughout the day and night. A small, reusable transmitter connects to the sensor wire and sends real-time readings wirelessly to a receiver, so the user can view the information. With some systems, a compatible smart device with the CGM system app can serve as the display device. The receiver or compatible smart device displays current glucose levels, as well as historical trends in levels. The CGM receiver and/or compatible smart device can also be set to send custom alerts to the user when certain glucose thresholds are reached.

## 4. CONCLUSION

With the development of wireless sensor network and micro electro mechanical systems technologies, intelligent sensors are developed to be embedded in remote locations such as structural health monitoring sensors embedded in the bridges, medical sensors implanted in the human body, A CGM (Continuous Glucose Monitor) device that provides "real-time" glucose readings and data about trends in glucose levels. Reads the glucose levels under the skin every 1-5 minutes (10-15 minute delay).Provides alarms for high and low glucose levels and trend information for diabetes management. Obtaining the sensors to replace the batteries could be very time-consuming and expensive. In the embedded case, the accessibility is even impossible and destructive. If a strain energy scavenging technology is realized, the life spans of those sensors could be extended significantly or even the batteries themselves could be replaced.

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